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Abstract

With Ultra-High Frequent JPY against UDS rate data, we investigate the features of the market microstructure of foreign exchange rate in terms of duration, volatility, volume and orderflow. ACD model developed by Russell/Engle (1995) enables us to use tick-by-tick type foreign exchange data without any loss of information. In addition to ACD model, we use GARCH type model modified to accomplish our purpose.

With ACD model, we found clear results. We confirmed that persistency of expected duration is strong. Thus, we cannot say foreign exchange market is efficient. As for the market microstructure exploralation, we use Diamond/Verrecchia (1986) model which shows that no trade means bad news, and Easly/O'Hara (1992) model which mentions that no trade means no news. Our results show that volume has significant negative impact on duration and buying USD orderflow also affects negatively on duration. If we can recognize volume and orderflow as the proxy of information inflow, foreign exchange market can be seen as the market Easly/O'Hara (1992) shown. The bigger the volume becomes, the shorter the trade interval becomes, the shorter the

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duration becomes, then the more the trade occurs.

In the next step, we analyze the relations between volatility and duration to explore the foreign exchange market structure. Duration has negative effect on volatility, but has no effect on foreign exchange rate in 2007, whereas duration has positive effect on volatility with negative effect on USD rate in 2008. If we take the result from ACD into account, the more information comes to market and the more trade occurs, the higher volatility becomes in 2007. This result is consistent with the implication from mixture of distribution hypothesis and Easly/O'Hara (1992) model. In 2008, the longer the trading interval becomes, the higher the volatility becomes. From ACD estimation, volume has positive impact on duration. Combining with these results, we can say that no trade, which means no news, makes market volatile. This result suggests that Diamond/Verrecchia (1986) model is valid. Uncertainty in the market was quite high and USD used to depreciate with active trade in our data in 2008. It might be said that foreign exchange market can be the market suggested by Easly/O'Hara (1992) in a usual case, but it also depends on the market condition such as uncertainty or risk.

Keywords: market microstructure, autoregressive conditional duration model

1. Introduction

In this paper, we tried to explore the market microstructure of foreign exchange rate with Ultra-High Frequency data. Many researchers have been doing enthusiastic works in this field. But not so many works have been done in foreign exchange market. This is partly because the difficulties of data availability. Data Mine (provided by ICAP Inc.) enables us to use market data in foreign exchange market. ICAP Inc. is providing trading platform through Internet. Today, almost all major market makers are using this trading platform and ICAP's database can cover all trading records such as foreign exchange rate, time, volume, buying or selling order indicator and order book at which trade is done. Before we got to use Data Mine, it was almost impossible to use market data regarding foreign exchange rate.

Among many techniques to analyze ultra high frequency tick-by-tick type data, there are two ways that are easy to use. One of the easiest ways is to convert raw data into even spaced data. With this method, we lose important information. For example, if we construct 5 minutes interval data from tick-by-tick data, only one data in 5 minutes will be picked up. The data we use in this paper contains the trading records with every 250 milli-second interval. We may abandon at most 18000 data in every 5 minutes. For avoiding this matter, we intend to use Autoregressive Conditional Duration model (ACD thereafter) developed by R.Engle and J.Rusell (1995). They proposed ACD model to model the interval between trades analogous to survival analysis and they defined the interval between the trades as duration.

In this paper, we utilize Log ACD (2,2) model and GARCH type representation with Ultra-High Frequency data, the latter method is developed and proposed by Engle (1996). By these models, we investigate dealers' trading activities in terms of duration, volatility, volume and orderflow. As Clark (1973) stressed that volume can be the good proxy of information inflow. Lyons (2001) found that orderflow plays more informative work in the market. In this paper, we first check the information contents of duration with volume and orderflow through ACD model. Then combining with ACD results with GARCH type model results, we will explore the market microstructure with duration, volume and orderflow.

The period we use here covers the event, Lehman's shock. Our data set spans from 1^{st} of July to the end of September in 2007 and 2008. We can use the result from 2007 data as the benchmark for investigating special features during Subprime shock days. In Susai (2009), we found some noteworthy features among USD, EUR and JPY currencies in Subprime period. Especially during the Lehman's shock, the relations among these most traded financial assets in the world were much different than that in same period in 2007.

For exploring the microstructure of foreign exchange market, we use the basic ideas proposed by Diamond/Verrechia (1986) and Easly/O'Hara (1992). Those models are good to explain the duration between trades. In Diamond/Verrecchia (1986), they thought that there exists two kinds of dealers, informed and uninformed traders. Suppose that informed dealers have private negative information on USD, and if USD rate depreciate with some bad news on USD, then informed trader might wait for next chance to trade to utilize their informational advantage. In this situation, longer duration means that bad news comes to informed dealers. On the other hand in Easly/O'Hara paper, if some portion of dealers have some informational advantage, these informed dealers do not want to trade without any new profitable information. In this case, longer duration means no crucial event occurred. These two models are really the idea we are going to test with empirical method.

The rest of this paper contains four sections. In the next section, we present Data Mine in detail. After the data description, we develop our model. In the section of results and discussion, we analyse market microstructure in terms of duration and two models mentioned above. We conclude our discussion in the last section.

2. Data

Real traded data has been difficult to use in foreign exchange market. In this paper, we use really traded market data, Data Mine ver.5. This data set provides us the foreign exchange rate at which dealers actually trade, bid or ask indicator, volume and order book in 250 millisecond interval. As we know, more than 70% dealers in banks and financial institutions in the world are trading through the trading platform operated by ICAP Inc.. The earlier versions of Data Mine do not contain volume and order book.

In this paper, we call this kind of data as "deal data". The intervals of deal data are uneven. Uneven interval data might have some trouble when we estimate the model with usual time series methods. Here we use ACD and GARCH type model proposed by Engle (1996) to deal with uneven spaced Ultra-High Frequency data problem.

Our data spans from 1st of July to 30th of September in 2007 and 2008. In these periods, Lehman Brothers failure had occurred in September, 2008. Because we had so called Subprime problem from July to September in 2008, we chose same period in 2007 as the baseline for comparison. By using the data in same month in different years, we can control month of the year effect. In 2007, we use more than 1 million records, and more than 1.2 million in 2008.

In our research, we use Japanese Yen against US Dollar rate. We also use transaction time, transaction volume and bid or ask indicator. At first, we define the duration between trades. Let t_i be the transaction time at time i and be $\tau_i = t_i - t_{i-1}$ as duration between trades.

With the bid or ask indicator, we affirm the direction of trade. For example, if bid indicator is assigned to a USD rate, this means the bid side of the

USD rate is hit by the counter part of the trade. This trade may have downward pressure to the USD rate. For these reasons, we use bid or ask indicators as the price pressure indicator and can be recognized as orderflow direction index. Trading volume also has impact on price movement. Bigger volume usually has bigger impact on price movement. We use the volume of

Table 1 Seasonality of Duration in 2007 and 2008

	2007		2008	
Variable	Coef.	t-Stat.	Coef.	t-Stat.
C	7.79E-05	3.97*	1.94.E-04	10.16*
D1	-2.86E-05	-0.54	-1.31.E-04	-2.67*
D2	-8.63E-06	-0.32	-2.08.E-04	-8.33*
D3	-8.85E-07	-0.03	4.60E-05	1.86***
D4	-4.56E-06	-0.18	4.32E-05	1.78***
D5	4.54E-06	0.19	-4.10E-06	-0.19
D6	-3.43E-06	-0.17	3.10E-05	1.74***
D7	-1.08E-05	-0.63	2.22E-06	0.15
D8	-9.72E-06	-0.56	-4.69E-06	-0.31
D9	2.89E-05	1.54	-1.23E-05	-0.76
D10	-6.12E-06	-0.32	-1.03E-05	-0.60
D11	-3.86E-05	-2.01**	1.17E-05	0.69
D12	2.92E-05	1.67	2.09E-05	1.38
D13	-2.46E-06	-0.16	2.43E-06	0.19
D14	-6.14E-06	-0.43	1.43E-06	0.12
D15	-2.45E-05	-1.57	-1.13E-05	-0.84
D16	2.87E-05	1.47	-2.24E-05	-1.33
D17	-1.79E-05	-0.78	-7.89E-06	-0.41
D18	5.62E-06	0.24	5.29E-06	0.27
D19	1.92E-05	0.81	-3.75E-05	-1.79***
D20	9.97E-06	0.35	-1.71.E-04	-6.72*
D21	-1.97E-06	-0.06	-5.58.E-04	-17.49*
D22	-2.54E-06	-0.08	6.44.E-04	19.81*
D23	-1.66E-05	-0.59	-9.56E-06	-0.35

Independent variable is duration in each equation

*:1% **:5% ***:10%

bid trade multiplied by bid indicator (-1) and ask trade multiplied by ask indicator (1). This amount can be recognized as orderflow in each trade. These variables might have impact on duration through the impact on USD rate movement.

In the first step, we check the seasonality of duration. Many papers which use stock data usually check the seasonality during daytime when the market is opened. As for the foreign exchange trade, dealers can trade at anytime of the day. Even in the weekend, dealer can trade if he or she can find the counterpart. 24 hours continuous trading is one of the famous features in foreign exchange market. For this reason, we check the seasonality of duration with 23 time dummies. The results are shown in Table 1 from equation (1).

$$\tau_t = c + \sum_{i=1}^{23} \alpha_{ti} D_{ti} + \varepsilon_t \qquad (1)$$

D_is are dummy variables and D_1 takes 1 from 0:00:00 to 0:59:59 (GMT) and 0 otherwise. ε_t is a error term and assumed normally distributed. In 2007, no strong seasonality is found. We may say some from 0:00:00 to 5:59:59 in 2008. This is Tokyo (or Asia) time zone. At the beginning of Tokyo market, durations might be shorter than other time zone. Tokyo is

Table 2 Market Effect

	2007		2008	
Variable	Coef.	t-Stat.	Coef.	t-Stat.
C	7.88E-05	13.43*	1.10E-04	21.29*
TOKYO_D	-2.94E-06	-1.52	-5.78E-07	-0.34
LD_D	-9.25E-07	-0.33	9.92E-06	4.16*
LD_NY_D	-7.92E-07	-0.31	-2.39E-05	-10.83*

Independent variable is duration in each equation

*:1% **:5% ***:10%

the first market that starts in a day. The trades are active during these 2 hours partly because dealers may adjust their positions at the beginning of the day.

Table 2 shows the market effect on duration. TOKYO_D covers from 0:00:00 to 8:59:59, LD_D covers from 9:00:00 to 12:59:59, and LD_NY_D covers from 13:00:00 to 15:59:59. As in the Table 1, we cannot find any seasonality in 2007, but find a clear seasonality in 2008. During London time, duration might be longer than any other market time zone. And duration has shorter tendency in the zone when London and New York are both

Table 3 Correlation Matrix in 2007

	INT	DLUSD	R_VOLATILITY	VOL	O_F
INT	1 -----				
DLUSD	0.0015 11%	1 -----			
R_VOLATILITY	0.0009 33%	-0.020 0%	1 -----		
VOL	-0.0008 43%	-0.023 0%	0.029 0%	1 -----	
O_F	0.0009 36%	0.402 0%	-0.0097 0%	-0.042 0%	1 -----

Table 4 Correlation Matrix in 2008

	INT	DLUSD	R_VOLATILITY	VOL	O_F
INT	1 -----				
DLUSD	-0.0062 0%	1 -----			
R_VOLATILITY	0.0065 0%	-0.040 0%	1 -----		
VOL	-0.0029 0%	-0.012 0%	0.0189 0%	1 -----	
O_F	-0.0005 59%	0.3404 0%	-0.0069 0%	0.039 0%	1 -----

active.

Correlations among variables can be checked in Table 3 and 4. INT represents duration, DLUSD is log difference of USD rate, R_VOLATILITY shows realized volatility (squared DLUSD), VOL is volume, and O_F is orderflow. USD rate change and volume are negatively correlated with duration. But realized volatility is positively correlated with duration. Former relations are intuitively understandable. In a given time period, high volume comes with active trade, and active trades shorten duration.

For eliminating the seasonality from duration data, we convert the raw data to seasonality adjusted data through equation (2).

$$\hat{\tau}_1 = \frac{\tau_i}{\psi(t_i)} \tag{2}$$

$\hat{\tau}$ is adjusted series and $\psi(t_i)$ is smoothed value at time i. To get $\psi(t_i)$ series, we use exponential smoothing with Hold-Winters additive seasonal variation method. Hereafter, we use seasonality adjusted duration in all estimations.

3. Model

ACD Model

Following many papers that use ACD model[1], we develop the model. Let s_i be the log first difference of USD rate and $f(\cdots|\cdots)$, $g(\cdots|\cdots)$ and $q(\cdots|\cdots)$ be the conditional density functions. We can define the conditional joint density function of s_i and $\hat{\tau}_1$ as follows.

$$f(s_i, \hat{\tau}_1|s^{(i-1)}, \hat{\tau}^{(i-1)}) = g(s_i|s^{(i-1)}, \hat{\tau}^{(i)})q(\hat{\tau}_1|s^{(i-1)}, \hat{\tau}^{(i-1)}) \tag{3}$$

1 ACD model was originally induced by Engle/Russel(1995).

As in the equation (3), conditional joint density function of s_i and $\hat{\tau}_1$ can be express by the product of $g(\cdots|\cdots)$and $q(\cdots|\cdots)$. In equation(3), $s^{(i-1)}$ and $\hat{\tau}^{(i-1)}$) are past information of s and $\hat{\tau}$ at time i-1.

Following Engle/Russel(1995), we assume,

$$\hat{\tau}_1=\Psi_i\,\varepsilon_i, \qquad \varepsilon_i\sim\text{i.i.d.} \tag{4}$$

This assumption allows us to describe the duration as mean function of Ψ_i. In this paper, we adopt Log ACD model as follows.

$$\ln(\Psi_i)=\omega+\sum_{j=1}^{n}\alpha_i\,\hat{\tau}_{i-j}+\sum_{j=1}^{m}\beta_j\ln(\Psi_{i-j})+\sum_{j=1}^{k}\rho_j z_{i,j} \tag{5}$$

z_is are exogenous variables. As we mentioned in Data section, we incorporate volume and orderflow as exogenous variables.

With (4) and (5), we can derive the quasi-likelihood function to estimate hazard function of $\hat{\tau}_i$.

$$\ln L=-\sum_{i=1}^{N}\ln\Psi_i+\frac{\hat{\tau}_i}{\Psi_i} \tag{6}$$

GARCH type Model

ACD model was proposed to analyze the uneven spaced Ultra-High Frequency data to estimate behavioral finance model or to test market microstructure hypothesis. As we have already confirmed that ACD model is modeling time interval between each trade. So, many papers including the papers in mixture of distribution hypothesis research are intending to analyze this relation. Following Engle(1996), we construct ARCH type model with Ultra-High Frequency data to test market microstructure in terms of Diamond/Verrechia(1986) and Easly/O'Hara(1992).

Let σ_i^2 be the conditional variance of the process per second and h_i be the conditional variance of individual trade. We assume that these two conditional variances are related as follows.

$$h_i = \hat{\tau}_i \sigma_i^2 \tag{7}$$

If s_i only depends on past information, the expected variance of s_i can be written as follows by using equation (4).

$$E_{i-1}(s_i^2) = E_{i-1}(h_i) = E_{i-1}(\hat{\tau}_1 \sigma_i^2) = \Psi_i \sigma_i^2 \tag{8}$$

$$\sigma_i^2 = \omega + \alpha \frac{\varepsilon_{i-1}^2}{\hat{\tau}_{i-1}} + \beta \sigma_{i-1}^2 \tag{9}$$

Equation (9) can be seen as GARCH type expression with Ultra-High Frequency data. With this conditional variance equation and mean equation of s_i, we can test the microstructure of foreign exchange market.

4. Results and Discussions

For accomplishing our research objectives, we employ ACD (2,2) model as below.

$$\begin{aligned} \ln(\Psi_i) = \omega + \sum_{j=1}^{2} \alpha_i \hat{\tau}_{i-1} \\ + \sum_{j=1}^{2} \beta_j \ln(\Psi_{i-j}) + \gamma_1 s_{i-1} + \gamma_2 s_{i-2} + \rho_1 vol_{i-1} + \rho_2 of_{i-1} + v_1 D_T \\ + v_2 D_{ld} \end{aligned} \tag{10}$$

We incorporate USD rate of change (s_{i-1}, s_{i-2}), volume (vol) and orderflow (of) variables as exogenous variables, and add two dummy variables for Tokyo and London time zone. If past duration has some impact on future expected duration, α_i should be significantly estimated. If past foreign exchange rate change makes some effects on future expected duration, γ_i should be significant. Volatility can be measured by s_i and volume. High s_i can cause volatile market. As with the prediction of mixture distribution hypothesis, if volume co-moves with volatility, high volume also comes with high volatility.

From the discussion of Clark (1973), volume can be the proxy of information inflow to the market. On the other hand, Evans/Lyons (2002, 2006) suggests that orderflow represents richer information than that volume has. It might be true because orderflow consists of order direction and volume. Therefore, orderflow comprises the information contained in volume. By checking the estimated parameter ρ_i, we can compare the informativity of volume and orderflow.

$$s_i = c + \lambda_i \hat{\tau}_i \tag{11}$$

$$\sigma_i^2 = \omega + \alpha \frac{\varepsilon_{i-1}^2}{\hat{\tau}_{i-1}} + \beta \sigma_{i-1}^2 + \theta_1 \frac{\zeta_{i-1}}{\Psi_{i-1}} + \theta_2 \frac{\tau_i}{\Psi_i} + \theta_3 \hat{\tau}_i + \theta_4 \Psi_i^{-1} \tag{12}$$

In equation (12), ζ_i is a long run volatility. We compute long run volatility as exponential smoothing series of realized volatility, s_i^2. λ_i can capture simultaneous relation between duration and foreign exchange movement in (11). θ_1 can measure the impact of long run volatility and many kinds of past durations on volatility. θ_2 captures the surprise component of duration. Rise of this variable means that relative length of actual duration to expected duration becomes longer. The difference between actual and expected terms might be thought as surprise.

All parameters are significantly estimated in both years. The sign of parameters are also almost same. Past durations and past expected dura-

2 See Engle (1996) in detail.

Table 5 Estimation Results of ACD(2,2)

	2007		2008	
	Coef.	z-Stat.	Coef.	z-Stat.
ω	1.2.E-02	38019*	1.2.E-02	393973.1*
α_1	1.2.E-01	88823.46*	1.2.E-01	159.53*
α_2	-1.4.E-04	-347.19*	-8.3.E-05	-4.36*
β_1	1.3.E-01	2782.54*	1.0.E-01	29.25*
β_2	-3.6.E-03	-72.03*	-1.3.E-03	-7.75*
γ_1	-5.8.E-02	-10.73*	1.1.E-01	41.05*
γ_2	-1.5.E-01	-25.85*	-1.4.E-02	-6.13*
ρ_1	-5.8.E-06	-56.73*	-1.6.E-05	-75.32*
ρ_2	-3.7.E-06	-46.39*	-6.7.E-06	-68.86*
ν_1	1.8.E-05	75.51*	2.3.E-06	16.47*
ν_2	-4.0.E-06	-15.50*	-3.4.E-06	-26.05*
Log likelihood	-2.2.E+07		-3.5.E+07	

*:1% **:5% ***:10%

tions have positive impact on future expected duration. If dealers face longer duration, or if they expect longer duration, these facts cause future longer expected duration. Persistency of the effect of past expected duration is quite big. Persistency can be captured by $\beta_1+\beta_2$. In both years, these values exceed 1. This means that the effect of past expected duration lives longer.

If we follow the Clark (1973) discussions, volume can be used as the proxy of information inflow, and more information that comes to market causes heavier trade, thus higher volume. With the parameters of volume and orderflow in Table 5, we can discuss the hypothesis proposed by Easly/O'Hara (1992) and Diamond/Verrecchia (1986). The more information comes to market, the heavier the trades occur if Easly/O'Hara (1992)'s hypothesis dominates.

As in the Table 5, volume and orderflow have same effects in both years.

Past volume makes future expected duration shorter. Orderflow in the past has negative impact on future expected duration. In this case, buying USD order shortens the duration. From these results, we can confirm that higher volume shortens the duration. If dealers trade with new information, this result is in line with the discussion in Easly/O'Hara(1992). During the period that more information comes to market, heavier trade occurs, hence duration becomes shorter.

Buying orderflow also makes duration shorter. In general, buying order should have positive impact on price. This tendency is consistent with the fact that used to be found in many financial markets. Price can be rise with more active trade and price used to drop with thinner trade. If dealers with good news on US dollar buy USD actively, then active buying orders make duration shorter. This fact is also in line with the discussion of Easly/O'Hara (1992).

Only the impact of foreign exchange rate change is opposite in both years. Appreciation of USD has negative impact on future expected duration in 2007. But the impact in 2008 is opposite. If dealer's reaction in terms of duration can be understood as their evaluation of the event, the appreciation of USD can be taken as good news in 2007, but not in 2008. The difference of the market condition in both years is the Lehman and Subprime shock. A lot market participant might be thinking that USD belongs to higher risk asset class in 2008. Buying USD orders raise USD value and accumulate USD long position at the same time. Position seems to be crucial role in financial market[3]. If higher USD or longer USD position means higher risk in 2008 than that in 2007, appreciation and accumulation of USD might be understood as worse news in 2008. This tendency might be also good for the

3 See the discussions in Lyons (2001).

Table 6 Estimation Result of GARCH type Model

	2007		2008	
	Coef.	z-Stat.	Coef.	z-Stat.
Mean Equation				
C	-5.9E-08	-0.64	8.2.E-07	9.50*
λ	-6.0E-09	-0.12	-1.0E-06	-16.09*
Variance Equation				
C	4.8E-09	36.82*	4.2.E-09	1858.89*
α	-3.9E-14	7.50*	4.9.E-06	617.08*
β	1.7E-01	-0.14*	6.9.E-02	269.13*
φ_1	-7.0E-09	-21.72*	2.7.E-08	169.01*
φ_2	4.5E-12	37.01*	-7.9.E-12	-79.50*
φ_3	-8.1E-11	-26.77*	1.5.E-09	398.64*
φ_4	-5.2E-13	-2.96*	2.0.E-12	42.54*
AIC	-16.185		-16.012	
SBIC	-16.185		-16.012	

*:1% **:5% ***:10%

Easly/O'Hara(1992) implications.

In terms of the market microstructure, we can get some implications from Table 6. In the first step, we check the result in mean equation (11). Duration does not have any impact on USD change in 2007, but has negative significant impact in 2008. Longer duration causes USD to depreciate. If dealers take the longer duration as bad news on USD, JPY/USD rate moves downward.

Almost all parameters have different signs in both years. The mean value and standard deviation of long run volatility in 2007 is smaller than those in 2008. Besides that, the mean and standard deviation of expected duration in 2008 is much higher. In both indicators, market conditions in 2008 are much worse, higher volatility and longer duration, which means more risky and more bad news may exist. This difference might have some effect on this discrepancy. But, still we have to do more research on the reason for this discrepancy.

ψ_1 represents the effect of long run realized volatility on volatility. Long run volatility has negative impact in 2007, and positive impact in 2008.

As for the effect of three kinds of durations on volatility, the sign of all these parameters are different in both years. In 2007, surprise and expected duration cause higher volatility and realized duration has negative impact on volatility. It is easy to guess that unexpected bad news and its expectation cause higher volatility if we can relate unexpected part of duration to unexpected bad news. Longer duration means fewer trades in a given time. Therefore, longer duration leads to lower volatility.

We can confirm that this results support Easly/O'Hara(1992) hypothesis. No news come with fewer trade, thus lower volatility. The results from ACD showed that high volume causes short duration. Combining ACD results with GARCH type results, we can confirm that volatility becomes small when trading activity is low, in other word duration is long. These relations show that Easly/O'Hara(1992) model is valid.

But in 2008, we might say that dealers act as shown in Diamond/Verrecchia(1986). The results in mean equation showed that longer duration causes USD depreciation. In other word, longer durations may contain bad news on USD value. We might say from this tendency that no trade means bad news on USD in 2008. Because high volume comes with short duration and buying order comes with also short duration as are mentioned in ACD results in 2008. Actually, our data period in 2008 covers Lehman's shock and bankruptcy of many US private banks. This event can be seen as extraordinary in one or more decades. In such a case, uncertainty among market participants should be high. In highly uncertain market, a dealer might wait for next chance that he or she decides to trade. In Diamond/Verrecchia (1986), informed dealer dose not want to trade with bad news, and wait for next opportunity to make use of his or her informational advantage. Thus, bad news come with longer duration in Diamond/Verrecchia(1986) model.

From these discussion, we cannot confirm that foreign exchange market has microstructural feature defined by Diamond/Verrecchia(1986) or Easly/O'Hara(1992). But we might say that market microstructure cannot be stable and can be strongly affected by market conditions such as uncertainty or risk condition.

5. Summary

With Ultra-High Frequent JPY against UDS rate data, we investigate the foreign exchange market microstructure in terms of duration, volatility, volume and orderflow. ACD model developed by Russell/Engle(1995) enables us to use tick-by-tick type foreign exchange data without any loss of information. In addition to ACD model, we use GARCH type model modified for analyzing tick-by-tick data.

As for the daily seasonality of duration, we found some features in Tokyo (or Asian) time zone, London time zone and London and New York time zone. Especially in London time, duration might be a bit longer than those in any other zone. One of the candidates of the reason to explain this tendency is the way we use in explaning of the JPY against USD rate in London market. In London market, major currencies they usually trade is GBP or EUR. Therefore, JPY_USD rate can be traded mainly for cover trade.

With the ACD model, we found clear results in both years. In both years, we confirmed that persistency of expected duration exists. From this result, we should be doubtful about the market efficiency. As for the market microstructure discussion, the impact of volume and orderflow shows the results for Easly/O'Hara model. If volume and orderflow can be used as proxy for information inflow into market, high volume and orderflow should be with short duration under the Easly/O'Hara model. $\rho_i (i=1,2)$ represent the impact of volume and orderflow and are negative and significant in equation (10). With these considerations, we can conclude that dealers in foreign market trade with information and in the manner Easly/O'Hara model suggested.

With GARCH type model, we explore market microstructure by analyzing the relations among volatility, duration and expected duration. It is clear that realized duration, surprised part of duration and expected duration have significant effect on volatility. Long run realized volatility also affects volatility. But the ways these durations and long run volatility affect on volatility are different in 2007 and 2008. In 2007, the relations show that market microstructure can be featured by Easly/O'Hara model. But in 2008, market feature is completely different, the signs of key parameters are opposite comparing to those in 2007. Market microstructure in 2008 can be seen as the one Diamond/Verrecchia suggested. We might be able to suggest that market microstructure can be affected by market conditions such as uncertainty or risk.

Volatility in 2007 is higher with active trade, but is higher with inactive trade in 2008. Clark and many researchers are showing that active trade comes with high volatility. This is true in our result only in 2007. The reason for this difference may stem from Subprime and Lehman's shock. In highly uncertain market, foreign exchange rate may move a lot in thinner market.

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